Contents

Acronyms and Abbreviations

Central Valley Water Board	Central Valley Regional Water Quality Control Board
Fe[II] or Fe^{2+}	ferrous iron
FeS	iron sulfide
Hg II	oxidized mercury
QA/QC	quality assurance/quality control

3.4.2.2 Conservation Measure 12 Methylmercury Management

*[**Note to Reviewers:** This text is proposed for Conservation Measure 12 Methylmercury Management . It has been completely revised from the November, 2010 draft version, so revisions are not shown. This measure is focused solely on the problem of methylmercury contamination arising from existing mercury loading caused by natural and historical sources in watersheds tributary to the Delta. Other conservation measures address water and sediment quality issues. It summarizes the best currently available information on methylmercury management, but is not intended to provide an explicit description of each component project. That information will appear in site-specific project proposals. The assumptions regarding the footprints and components of all conservation measures are described in Chapter 5,* Effects Analysis.*]*

Conservation Measure (CM) 12 Methylmercury Management will minimize conditions that promote production of methylmercury in restored areas and its subsequent introduction to the foodweb, and to covered species in particular. This conservation measure will promote the following actions.

- Define design elements that minimize conditions conducive to generation of methylmercury in restored areas.
- Define adaptive management strategies that can be implemented to monitor and minimize actual post-restoration mobilization of methylmercury.

The design elements will be integrated into site-specific restoration designs based on site conditions, community type (tidal marsh, nontidal marsh, floodplain), and potential concentrations of mercury in prerestoration sediments. The adaptive management strategies can be applied where site conditions indicate a high probability of methylmercury generation and effects on covered species.

3.4.2.2.1 Purpose

The primary purpose of CM 12 Methylmercury Management is to meet or contribute to biological goals and objectives as identified in Table CMX-01 *[**Note:** These goals and objectives are still in development, so the table is not presented in this draft]*. The rationale for each of these goals and objectives is provided in Section 3.3, *Biological Goals and Objectives*. Through effectiveness monitoring, research, and adaptive management (Section 3.5, *Adaptive Management and Monitoring Program*), the Implementing Office will address scientific and management uncertainties and help to ensure that these biological goals and objectives are met.

CM 12 will also provide benefits beyond those specified as biological goals and objectives. The techniques proposed in this conservation measure are expected to reduce methylmercury production in Delta wetland ecosystems, convert existing methylmercury to less-toxic inorganic mercury, or reduce the potential for methylmercury to enter the foodweb. Each of these outcomes will benefit all wetland communities and the covered species dependent on those communities.

3.4.2.2.2 Existing Conditions

Mercury is present in sediments and soils throughout the Delta, having been deposited by tributaries and rivers that drain areas of former mining operations in the mountains. The highest concentrations have been reported in Cache Creek and Yolo Bypass and the Mokelumne-Cosumnes

River system (Woods et al. 2010). Mercury is also potentially present in sediments of all ROAs throughout the Delta at varying concentrations.

Mercury in an inorganic or elemental form tends to adhere to soils and has limited bioavailability. Mercury may be converted by microbes to a different form, called methylmercury, which is much more bioavailable and toxic than inorganic forms, and has a strong tendency to bioaccumulate through the foodchain. The toxicity and tissue concentrations of methylmercury are amplified as it bioaccumulates through the foodweb. As a consequence, the filet mercury concentrations of most sportfish in the Delta exceed fish advisory guidelines.

Mercury is converted to methylmercury in a process called methylation by sulfur-reducing bacteria that occur in anaerobic (oxygen-depleted) conditions, such as are often found in wetland soils. Current research has shown that the conversion rate is highest in sediments subjected to periodic wet and drying-out periods, including marshes and floodplains. The highest methylation rates are associated with high tidal marshes (Alpers et al. 2008). The potential effects from mercury in the BDCP Plan Area are, therefore, highly dependent on the following conditions.

- In-place sediment (or flooded soil) concentrations of mercury, methylmercury, and organic compounds.
- The methylation rates of the surface sediments in restored environments.

Restoration actions proposed in CM 4 Tidal Habitat Restoration will increase the acreage of intermittently wetted areas by converting agricultural and other upland areas to tidal, open water, and floodplain habitats, potentially increasing methylmercury production in the Plan Area. Some of this increased production is likely to be taken up by organisms, and to bioaccumulate through the foodweb. The risk that mercury and methylmercury pose to covered species is discussed in Appendix D, *Toxins*.

3.4.2.2.3 Implementation

Required Actions

Project-Specific Mercury Management Plans

For each restoration project under CM 4 Tidal Habitat Restoration, a project-specific mercury management plan will be developed and will incorporate all of the methylmercury management measures discussed below or include an explanation of why a particular measure cannot be incorporated. The plan will include the following components.

- A brief review of available information on levels of mercury expected in site sediments (proximity to sources, existing analytical data).
- An estimation of the relative amounts of mercury expected in site soils.
- A determination if sampling for characterization of mercury concentrations and/or post-restoration monitoring is warranted.
- A plan for conducting the sampling, if characterization sampling is recommended.

To cover any sampling or monitoring, the project-specific mercury management plan will also include a quality assurance/quality control (QA/QC) program specifying sampling procedures, analytical methods, data review requirements, a QA/QC manager, and data management and reporting procedures. Each project-specific plan will be reviewed and approved by the QA/QC manager.

Because methylmercury is an area of active research in the Delta, each new project-specific mercury management plan will be updated based on the latest information about the role of mercury in Delta ecosystems or methods for its characterization or management. Results from monitoring of methylmercury in previous restoration projects will also be incorporated into the next project-specific mercury management plan.

Timing and Phasing

The timing and phasing of implementing CM 12 will be contingent upon the timing and phasing of individual restoration projects. One principal source of new information is anticipated to be a basin plan amendment currently in preparation by the Central Valley Regional Water Quality Control Board (Central Valley Water Board) (2011). Phase I of the basin plan amendment (effective October 2011) for methylmercury will be underway for the next 7 years, with an additional 2 years to evaluate Phase I results and plan for Phase II. The findings of research conducted under Phase I will be discussed in each of the project-specific mercury management plans and any new information on methylmercury mitigation measures will be considered and reviewed in the plan for application to that specific project.

Monitoring and Adaptive Management

Refer to Section 3.5, *Adaptive Management and Monitoring Program,* for a discussion of monitoring and adaptive management measures specific to this conservation measure. Post-construction monitoring of mercury will be mandatory if preconstruction monitoring data show levels of methylmercury exceeding 0.06 nanogram per liter (unfiltered sample).

Minimization and Mitigation Measures

Each project-specific mercury management plan will describe, at a minimum, the application or infeasibility of each of the mitigation measures described in detail in the following paragraphs.

Characterize Soil Mercury

Soil mercury will be characterized to inform restoration design, post-restoration monitoring, and adaptive management strategies. The amount of mercury that could be converted to methylmercury is directly related to the initial concentrations of mercury in restoration site sediments. Mercury is generally not homogenously distributed in alluvial sediments. Factors determining the distribution of mercury in an area include distance from source areas (tributaries carrying mercury from upland mining areas such as Cache Creek), sediment grain size (mercury preferentially adheres to fine-grained sediments in depositional areas), and distribution of channel versus overbank alluvial deposits. Sampling designs will account for these variables to assess mercury distribution throughout a restoration site. Outcomes of the characterization could include pre-restoration site preparation and remediation, selection and design of appropriate mitigation measures, and design of post-restoration monitoring requirements.

Further mitigation measures and post-construction monitoring will be mandatory if monitoring data show levels of methylmercury exceeding 0.06 nanogram per liter (unfiltered sample).

Minimize Microbial Methylation

Conversion of mercury to methylmercury depends on bacterial action in an anoxic environment. By reducing the amount of organic material at a restoration site, levels of bacterial action are lowered, and biological oxygen demand would also be lowered, resulting in the potential for more aerobic conditions. Recent research in the Yolo Bypass has demonstrated that methylmercury levels could be reduced by up to an order of magnitude by using livestock grazing to reduce loads of organic matter prior to flooding (Heim et al. in press). Therefore, livestock grazing will be applied in the appropriate season to remove as much vegetative material as is feasible prior to restoration to create conditions that limit the generation of methylmercury after flooding. Wetlands are complex systems that have evolved under anaerobic conditions and have developed communities of organizations that thrive under these conditions. For each area where removal of organic matter is considered, site-specific conditions and restoration objectives will be carefully evaluated to determine if the measure is appropriate and how it should be implemented.

To ensure an aerobic water column and surface sediment layer that will minimize mercury methylation two techniques will be used when feasible. First, water depths will be sufficient to avoid drying. Second, restoration sites will be designed to include shallow ponded areas with extensive open expanses to promote frequent wind-driven oxygenation (e.g., high wind fetch) that will minimize methylation. Emergent or submerged macrophytes will be removed, which also promotes mixing and aeration throughout the water column. Where feasible, ponds will be deep enough to discourage overgrowth by rooted macrophytes yet shallow enough to promote wind mixing and to allow significant light exposure to the mixed water column, which promotes photodegradation (see below).

Design to Enhance Photodegradation

Photodegradation has been identified as an important factor that removes methylmercury from the Delta ecosystem by converting methylmercury to the biologically unavailable, inorganic (nonmethylated) form of mercury. Photodegradation of methylmercury occurs in the photic zone of the water column (the depth of water within which natural light penetrates). At the 1% light level, the mean depth for the photic zone in the Delta was calculated to be 2.6 meters, with measured depths ranging from 1.9 meters to 3.6 meters (Gill 2008, Byington 2007). Gill and Byington also conclude that photodegradation may be most active within the top half-meter of the water column in the Delta. Gill (2008) identified photodegradation of methylmercury as potentially the most effective mercury detoxification mechanism in the Delta. In the methylmercury budgets developed by Woods et al. (2010), Foe et al. (2008), Byington (2007), and Stephenson et al. (2007), photodegradation rates of methylmercury exceed methylmercury production rates from sediment.

Once photodegraded, mercury will either be volatilized to the air (Amyot et al. 1994), hydrologically transported, or will become available for methylation once again. Once methylated, mercury would again be biologically available.

To maximize photodegradation rates, restoration sites will be maintained for as long as feasible at depths that do not exceed the photic zone.

Remediate Sulfur-Rich Sediments with Iron

Mercury is methylated by sulfate-producing bacteria that live in anoxic conditions found in tidal marsh restoration areas. Adding iron can reduce the activity of sulfide, thereby reducing mercury methylation. Ferrous iron (Fe[II] or Fe^{2+}) in sediment pore water can decrease the concentration of dissolved sulfide through the formation of iron sulfide (FeS) and other minerals. Because iron sulfide is the strongest ligand for oxidized mercury (Hg II) under anoxic conditions, the decrease in sulfide activity should result in a decrease in the concentration of soluble inorganic mercury that is available for methylation and, ultimately, for bioaccumulation. Research in laboratories has demonstrated that the addition of ferrous iron to pure cultures of sulfate-reducing bacteria in an anoxic system decreased net mercury methylation by approximately 75% (Ulrich 2011). Iron remediation to reduce methylation will have to be evaluated on a site-by-site basis. The evaluation will consider species-specific and community effects, fate and transport of the chemicals prior to implementation, and the cost/benefit of the remediation.

Cap Mercury-Laden Sediments

Some restoration areas may require application of fill to raise grades to design elevations. By covering the mercury-containing sediments with fill free of mercury, the wetting and drying cycles that promote methylation would be reduced or would not release methylmercury to the overlying water. At sites where this measure can be implemented, there will be no interface between the mercury-containing sediments and the water column, limiting methylmercury flux into the water column and exposure to biota. Depending on the depth of the added sediment layer, bioturbation, which mixes surface and near surface sediments, could bring the mercury back up near the sediment/water interface, limiting the effectiveness of this approach. Baseline characterization of mercury in sediments and post-restoration monitoring within the framework of an adaptive management program will be integrated into this measure.

3.4.2.2.4 References

Alpers, C. N., C. Eagles-Smith, C. Foe, S. Klasing, M. C. Marvin-DiPasquale, D. G. Slotton, and L. Windham-Myers, 2008. Mercury Conceptual Model. Sacramento-San Joaquin Delta Regional Ecosystem Restoration Implementation Plan.

Amyot, Marc, Donald J. McQueen, Greg Mierle, David R. S. Lean. 1994. Sunlight-induced Formation of Dissolved Gaseous Mercury in Lake Waters. *Environmental Science and Technology.* 1994, 28 (13), pp 2366–2371

Byington, A. 2007. Photo-degradation of Methyl Mercury in the Sacramento – San Joaquin Delta Estuary. Thesis Report Presented to Gary Gill to be Submitted to the CALFED Bay-Delta Program for the Project Transport, Cycling and Fate of Mercury and Monomethylmercury in the San Francisco Delta and Tributaries Task 5.1. Central Valley Regional Water Quality Control Board: Central Valley Region. Available: <http://mercury.mlml.calstate.edu/reports/reports/>.

Central Valley Regional Water Quality Control Board. 2011. Sacramento-San Joaquin Delta Methylmercury TMDL. Lat revised: November 9, 2011. Available: <http://www.waterboards.ca.gov/rwqcb5/water_issues/tmdl/central_valley_projects/delta_hg/> . Accessed: November 11, 2011.

Foe, C., S. Louie, and D. Bosworth. 2008. Methylmercury Concentrations and Loads in the Central Valley and Freshwater Delta. Final Report Submitted to the CALFED Bay-Delta Program for the Project Transport, Cycling and Fate of Mercury and Monomethylmercury in the San Francisco Delta and Tributaries Task 2. Central Valley Regional Water Quality Control Board. Central Valley Regional Water Quality Control Board: Central Valley Region. Available: <http://mercury.mlml.calstate.edu/reports/reports/>. Accessed: September 28, 2011.

Gill, G., 2008. Monomethylmercury Photo-Degredation Studies. Final Report Submitted to the CALFED Bay-Delta Program for the Project Transport, Cycling and Fate of Mercury and Monomethylmercury in the San Francisco Delta and Tributaries Task 5.1. Central Valley Regional Water Quality Control Board. Central Valley Regional Water Quality Control Board: Central Valley Region. Available: <http://mercury.mlml.calstate.edu/reports/reports/>. Accessed: September 28, 2011.

Heim, W. A., M. Stephenson, A. Bonnema, A. Byington, A. Newman, D. Feliz, L. Sousa, and K. Coale (In Press). Methylmercury Concentrations and Exports from Seasonal Wetlands in the Yolo Wildlife Area, California. Final Report.

Stephenson, M., C. Foe, G. Gill, and K.H. Coale. 2007. Transport, Cycling, and Fate of Mercury and Monomethyl Mercury in the San Francisco Delta and Tributaries: An Integrated Mass Balance Assessment and Approach. Calfed Mercury Project Annual Report.

Ulrich, Patrick D. (2011). Methylmercury Production in Tidal Salt Marsh Sediments and Potential Control Using Iron Amendments. UC San Diego: California Sea Grant College Program. Available: <http://escholarship.org/uc/item/9ms4z5hz>.

Woods, M., C. Foe, J. Cooke, and L. Stephen. 2010. Sacramento–San Joaquin Delta Estuary TMDL for Methylmercury. California Regional Water Quality Control Board: Central Valley Region.